Overview

This paper presents the procedures implemented to update the Indiana Model using traditional four-step models in support of the I-69 Evansville to Indianapolis Study Tier 1 EIS. The suite of analytical tools developed for the Major Indiana Corridor Investment Benefit Analysis System (MCIBAS), including the Indiana Statewide Travel Model (initial Indiana Model), formed the foundation for the updated Indiana Model developed specifically for the I-69 Evansville to Indianapolis Study.

The four-step model development procedures implemented as part of the initial Indiana Model were updated to represent 1998 and 2025 conditions for this study. In addition, significant model improvements were undertaken including the validation of each element of the modeling process (trip generation, trip distribution, mode choice, and trip assignment). Detailed model development and application procedures were consistent with the level of effort in the initial Indiana Model development process. Refer to the *Indiana Statewide Travel Model Documentation Report* prepared for INDOT on August 25, 1998, for detailed information on Indiana Model development procedures.

A brief summary of the major subjects described in the remainder of this technical report is provided, as follows:

- **Geographic Expansion and Regional Network / TAZ Refinements** The geographic coverage of the initial model was expanded significantly. In addition, major local jurisdictional roads in rural areas were added to the network and traffic analysis zones were appropriately subdivided throughout the 26-county I-69 Study Area.

- **Free-flow Speed Studies used to Develop New Link Speeds** Since accurate travel time estimates will be crucial to the analysis and comparison of alternative I-69 route concepts, extensive field studies were undertaken to develop a system for improving the accuracy of free-flow input speeds to the trip assignment process.

- **Improved Estimation of Link Capacities and Effective Travel Times** Geometric and traffic operational characteristics of network links within the 26-county I-69 Study Area were utilized for improved estimates of link capacities and effective travel speeds.

- **Modeling Elements Based on Four-Step Transportation Model Principles.** The incremental modeling process that was implemented in the initial Indiana Model was eliminated in favor of the traditional four-step travel demand model development and validation procedures. Previous modeling elements such as the estimation and validation of base year origin and destination trip tables, the foundation for the incremental modeling process, were replaced with four-step model validation procedures including trip generation, trip distribution, mode choice, and trip assignment. Each step of the original statewide travel demand modeling sequence was improved in some way. Updating the Indiana Model using four-step modeling procedures simplifies the model application process and ensures that state-of-the-practice modeling is maintained. These upgrades are described in detail in succeeding sections of this paper.

- **External Models and Cumulative Demand** The treatment of trips originating or destined to locations outside Indiana has been significantly changed in the I-69 model. Trips generated in the expanded model area were modeled as "internal" trips and trips generated in the rest of the country were obtained from the Corridor 18 Study Regional Travel Model.

- **Truck Models** The truck trip model developed for the original statewide model was largely left in tact with the exception of an improved process for disaggregating truck trip end from the county level to TAZs that considered employment and commodity type as estimated by the REMI model.

- **Trip Assignment Models and Validation** Following development of each component of the model, an extensive effort to validate the model's performance was undertaken. Statistical measures of model accuracy are reported.

- **Updated Socioeconomic Data to Reflect 1998 and 2025 Conditions.** Socioeconomic data representing 1998 conditions in Indiana and each adjacent state were coded into the updated Indiana Model zone system. This data was used as the basis for implementing and validating the four-step transportation models used to assess travel demand for the I-69 Evansville to Indianapolis Corridor Study. Future forecasts of socioeconomic data for 2025 were also input into the updated Indiana Model for future forecasting purposes. Both 1998 and 2025 socioeconomic data were incorporated for the entire zone system in the updated Indiana Model.

Detailed procedures required to run the updated Indiana Model are presented in the *Technical Report 3.3.1: Model Users' Guide Report* under separate cover. The *Users' Guide* was structured to identify the application methods of the core modeling components of the updated Indiana Model.

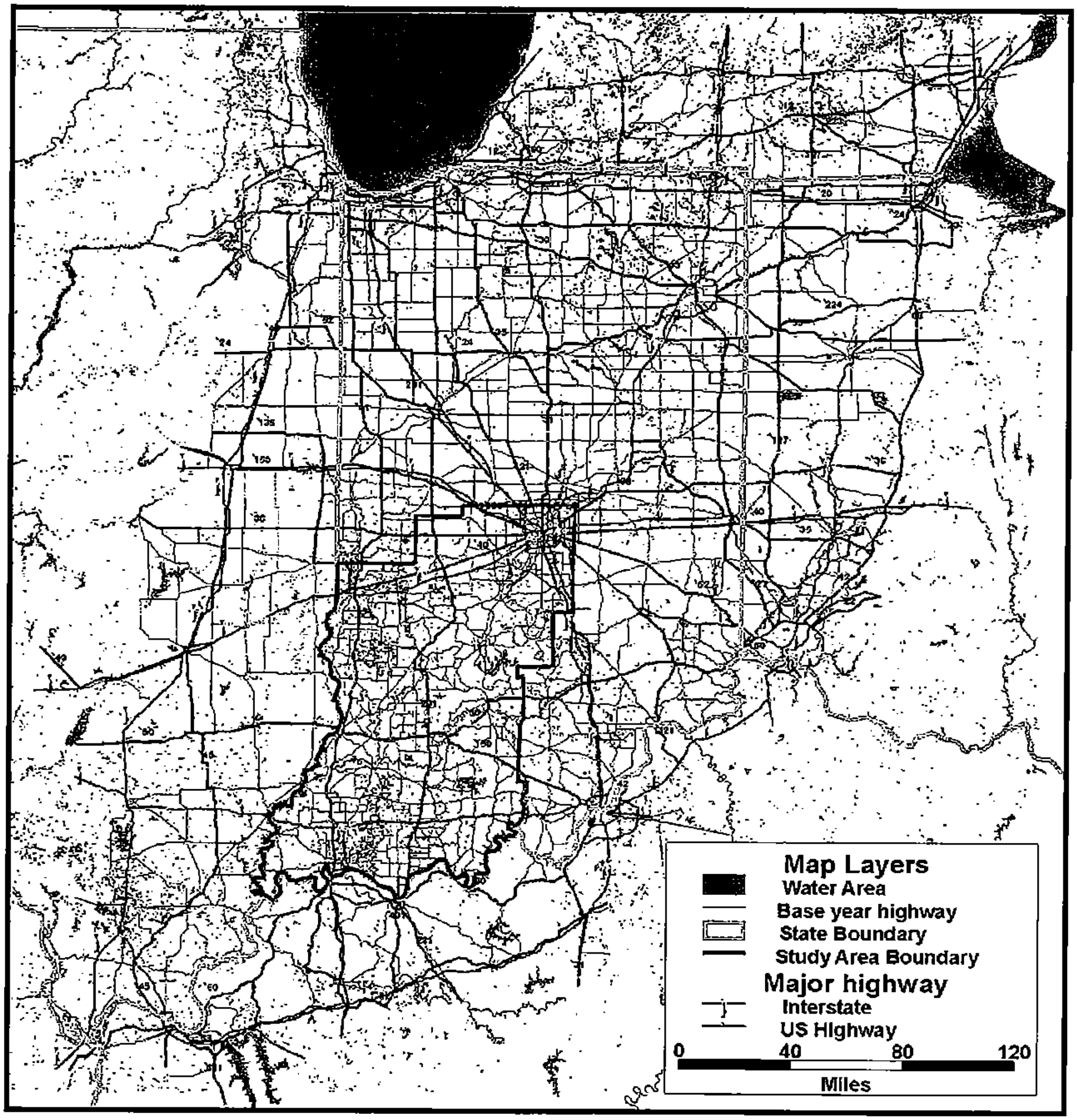
Model Expansion

The geographic coverage of the initial model was limited to the State of Indiana, plus limited additional network and external zones to represent the abutting major urban areas of Chicago, Louisville, and Cincinnati. It was decided that the geographic area for the new model needed to be dramatically expanded for three reasons.

- If completed nationally, the cumulative impacts of I-69 have the potential to affect the Interstate system in all of the neighboring states at least to a limited degree. The I-69 Tier 1 EIS will need to estimate these impacts.
- Certain I-69 corridor alternatives, notably alternatives that make use of all or a portion of US 41 between Evansville and Terre Haute, have the potential to affect the Illinois state highway system. The continued exclusion of eastern Illinois would underestimate traffic flows on these alternatives.
- I-69 considerations aside, it made sense that the next generation of the statewide model have the capability to assess the effects of land use and highway system changes in neighboring states on Indiana's highway network.

The expanded study area is shown in Figure 1.

Figure 1: Geographic Coverage of Updated I-69 Indiana Statewide Travel Model



Within Figure 1, the 26-county I-69 Study Area is circumscribed by the red line. Within the Study Area, all rural roads functionally classified as a "collector" or higher were added to the network and zones were subdivided to accommodate the more detailed roadway network. Outside of Indiana, traffic analysis zones are defined by county lines. The initial model had 651 internal zones and 110 external stations and external zones combined. The new, expanded model has x zones and y external stations.

Free-Flow Speed Studies

The original statewide travel model used posted speed limits as a surrogate for free-flow link speeds in the network skim and trip assignment processes. In most cases this practice under-represented the true free-flow input to the travel model. These speeds resulted in a significant overestimation of travel times. The alternatives analysis for I-69 will rely heavily on accurate travel times to compare travel time savings among alternative routes and to accurately model traffic flows among competing facilities within the same network. Accordingly, the decision was made to invest some effort in obtaining a sample of true free-flow speeds by functional class and to devise a revised free-flow link speed estimation process based on these real-world observations. This task was approached as follows:

a. Select survey locations;
b. Collect the field data (vehicle classification counts and speed);
c. For each location, estimate a median speed;
d. Eliminate the data which do not represent free-flow conditions from analysis;
e. Perform statistical analyses for the free-flow data to identify the relationships between free-flow speed and area type, functional class, terrain type and posted speed; and
f. Finalize free-flow speed table.

Free-Flow Speed Estimation

Field surveys on vehicle classification counts and speed were complete for a total of 64 survey locations in the southwestern Indiana (See Figure 1). The main purposes of these surveys are to estimate free-flow speeds, to update vehicle classification traffic counts and to investigate volume-delay relationships for the I-69 study area.

Data was collected in 15 minutes time periods for a span of 24 to 48 hours. The surveys were conducted with NU-METRICS traffic analyzers which were installed on the road surface at the survey spot. The analyzers can instantly record travel speed and classification data on the vehicles passing over.

Data collected by NU-METRICS are in a format of frequency distributions on speed class intervals. Those distributions from the survey show some "skewed" distributions, so taking a mean speed over the skewed data could over or under represent the actual average speed. One alternative to avoid this misinterpretation is to estimate a median value as follows:

$$\text{Median} = \text{LL} + (\text{interval width})\left(\frac{.5n - f_{below}}{f}\right)$$

where,

LL = lower *exact* limit of the interval
n = total number of data points
f_{below} = cumulative frequency below the lower exact limit containing the median
f = frequency for the interval

Table 1 shows actual median speed from the survey for each location (For survey locations, refer to Figure 2).

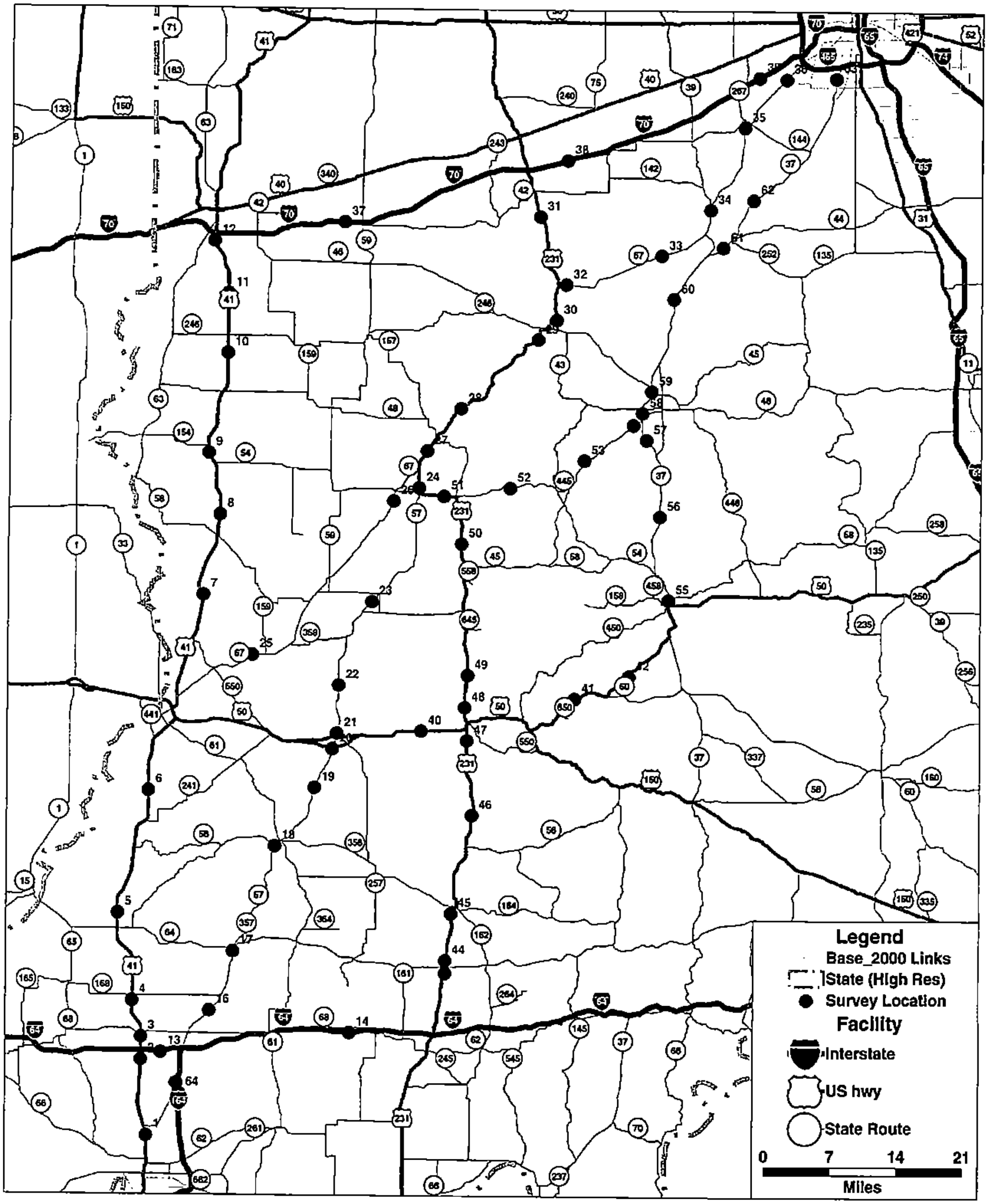


Figure 1. Locations for Traffic Counts/Speed Survey

Table 1 Vehicle Median Speeds from Field Survey

Survey Location	Facility	FHWA Func. Class*	Median Speed (mph)	Pick	Survey Location	Facility	FHWA Func. Class*	Median Speed (mph)	Pick
1	US 41	14	52.3	✓	33	SR 67	6	62.2	✓
2	US 41	2	51.1		34	SR 67	6	63.3	✓
3	US 41	2	43.2		35	SR 67	14	61.1	✓
4	US 41	2	44.1		36	SR 67	14	51.3	
5	US 41	2	67.4	✓	37	I-70	1	71.1	✓
6	US 41	2	59.9	✓	38	I-70	1	71.0	✓
7	US 41	2	69.9	✓	39	I-70	1	70.6	✓
8	US 41	2	61.3	✓	40	US 50	2	56.5	✓
9	US 41	2	33.5		41	US 50	2	47.5	
10	US 41	2	50.8		42	US 50	2	48.0	
11	US 41	2	61.1	✓	43	US 231	14	27.3	✓
12	US 41	14	50.2	✓	44	US 231	14	22.9	
13	I-64	1	65.8		45	US 231	14	29.3	✓
14	I-64	1	69.0	✓	46	US 231	2	55.3	✓
15	SR 57	6	61.9	✓	47	US 231	2	33.7	
16	SR 57	2	56.3	✓	48	US 231	2	55.9	✓
17	SR 57	2	39.8		49	US 231	2	54.8	
18	SR 57	2	21.7		50	US 231	2	55.4	✓
19	SR 57	2	62.8	✓	51	SR 54	2	32.1	
20	SR 57	2	52.0		52	SR 54	7	51.7	✓
21	SR 57	2	29.8		53	SR 45	7	53.2	✓
22	SR 57	7	59.1	✓	54	SR 45	14	48.4	✓
23	SR 57	7	50.3		55	SR 37	12	45.8	
24	SR 57	2	23.3		56	SR 37	2	53.2	
25	SR 67	6	60.1	✓	57	SR 37	2	62.1	✓
26	SR 67	6	24.2		58	SR 37	12	61.6	✓
27	SR 67	2	54.0		59	SR 37	12	48.8	
28	SR 67	2	59.7	✓	60	SR 37	2	61.9	✓
29	SR 67	2	29.1		61	SR 37	12	57.5	
30	SR 67	2	30.2		62	SR 37	2	67.2	✓
31	US 231	2	60.6	✓	63	SR 37	12	54.9	
32	SR 67	6	53.6	✓	64	I-164	1	69.3	✓

Source: Bernardin, Lochmueller & Associates, Inc.
Note: * FHWA Functional Class
1 – Rural Interstate, 2 – Rural Principal Arterial, 6 – Rural Minor Arterial,
7 – Rural Major Collector, 8 – Rural Minor Collector, 9 – Rural Local,
11 – Urban Interstate, 12 – Urban Freeway/Expressway, 14 – Urban Principal Arterial,
16 – Urban Minor Arterial, 17 – Urban Collector, 19 – Urban Local

The following major factors influence the vehicle travel speed:

- Geometrics of the road
- Posted speed

- Interference by traffic
- Interference by heavy vehicles
- Impact from traffic signal
- Weather conditions
- Special incidents

In its definition, free-flow speed is the speed that occurs when density and flow are zero. Thus, factors determining free-flow speed only include geometrics of the road and posted speed without any interference by traffic, signals, weather or accidents.

Because the field surveys were not designed solely for obtaining the free-flow data, a "filtering" of the survey data was needed to get the data that represent the free-flow conditions. 28 locations that could misrepresent the traffic flow conditions were eliminated from analysis. The remaining 36 locations were selected based on their survey location, area type, traffic volume at the time of survey and median speed compared to the posted speed.

In selecting those locations for analysis, the following criteria to determine the free-flow conditions were used based on the 1994 HCM:

- Freeway: Median speed of vehicles when flow rates are less than 1,300 pcphpl.
- Multi-lane highways: Median spped of passenger cars under low to moderate flow conditions (up to 1,400 pcphpl).
- 2-lane highways: no criterion for flow rates is given in the HCM. Assuming LOS B ~ LOS C conditions as free-flow conditions, 750 pcph in both directions was used.

The selected survey locations are identified in Table 1.

For the selected data, sequential levels of statistical analyses were implemented to estimate the speed table. At level 1, estimated median speeds by associated functional classes were compared to investigate if those speeds are significantly different. This investigation was facilitated by using the One-Way Analysis of Variance (ANOVA) technique. ANOVA compares the means of two or more independent groups with a null hypothesis that all means are equal. ANOVA examines both within-groups and among-groups variations to test the statistical differences among them. Within-groups variation reflects only inherent variation of individual scores about their sample means. On the other hand, among-groups variation addresses inherent variation plus differential treatment effect by means of variations of the sample means among groups.

Figure 3 shows the result of ANOVA. This result suggests that the null hypothesis can be rejected or that functional classes do not have the same mean speeds.

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                    One-Way Analysis of Variance
--------------------------------------------------------------------------------
Data: SPEED.Spd

Level codes: SPEED.FC

Labels:

Means plot: Conf. Int.     Confidence level: 95      Range test: LSD

                         Analysis of variance
--------------------------------------------------------------------------------
Source of variation  Sum of Squares   d.f.   Mean square    F-ratio  Sig. level
--------------------------------------------------------------------------------
Between groups            1933.9540      5     386.79080      4.113     0.0047
Within groups             3385.3579     36      94.03772
--------------------------------------------------------------------------------
Total (corrected)         5319.3119     41

0 missing value(s) have been excluded.
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Figure 3 ANOVA Result for Speed and Functional Class

At level 2 of the analysis to estimate the speed table, any possible relationships between the speed by functional class and terrain type were examined. This investigation was based on the non-parametric cross tabulation technique. Cross tabulation focuses on the interrelationships among variables in the form of two-way frequency distributions. This technique involves the formulation of a table which shows joint frequencies on two variables, considers the patterns of all frequencies and leads to a judgment as to whether the relationships are strong, weak or none.

Cross tabulation on two terrain types, flat and rolling, was applied to each functional class. This technique revealed that there is no evident relationship between terrain type and speed by functional class. For some data, rolling terrain indicated even higher speed than flat terrain. Thus, the speed survey did not lead to the differentiation between flat and rolling terrains.

At level 3, speeds between 2-lane 2-way road and multilane road (4 lanes or more) were differentiated. The field data clearly showed that speeds on the 2-lane roads tend to be slower than the multilane roads because of the limitations on the usage of right-of-way and on sight distance.

Based on the data analysis implemented so far, a speed table was developed with respect to area type, functional class, posted speed and the number of lanes, as shown in Table 2. Under the column "Average Speed" in Table 2, the average of median speeds for the facilities with the same functional class, posted speed, and number of lanes is listed. The average speed was compared with the free-flow speed recommended in "NCHRP Report 387: Planning Techniques to Estimate Speeds and Service Volumes for Planning Applications in 1997." This NCHRP report derives two separate linear equations for estimating free-flow speed based on curve fitting on collected datasets: one for facilities with posted speed limits that exceed 50mph; the other for facilities with lower posted speed limits. Under the column "NCHRP" are the outputs of the equations. With the comparison with the NCHRP recommendations and judgmental adjustments on the average speeds, free-flow speeds were determined as shown under the column "Free-Flow Speed."

Table 2 indicates that the mean free-flow speeds are on the average 4.94 mph higher than the posted speed limits for all facilities. In comparison, field surveys conducted for four rural freeways in California, Oregon and New Hampshire shows the average 5.6 mph over the posted speed. This analysis results 5.36 mph over the posted speed for rural interstate.

For selected locations, actual free-flow speeds were input in the base year highway network. For all other links in the network, "Speed Differential" as shown in Table 2 was applied. "Speed Differential" indicates the difference between the posted speed and actual vehicle speed over the posted speed in free-flow conditions. By specifying the differential instead of just showing the free-flow speed, the free-flow conditions in reference to the posted speed can be explicitly visualized.

Table 2 Free-Flow Speed Table

Area	Facility	FHWA Functional Class	Posted Speed (mph)	Number of Lanes	Avg. Speed (mph)	Free-Flow Speed (mph)	Speed [1] Differential (mph)	NCHRP [2] (mph)
Rural	Interstate	1	65	4	70.11	70.11	5.11	71.20
		1	65	6	70.60	70.60	5.60	71.20
	Principal Arterial	2	30	2		35.00	5.00	35.70
		2	30	4		36.90	6.90	35.70
		2	35	2		40.00	5.00	39.65
		2	35	4		41.90	6.90	39.65
		2	40	2		45.00	5.00	43.60
		2	40	4		46.90	6.90	43.60
		2	45	2		50.00	5.00	47.55
		2	45	4		51.70	6.70	47.55
		2	50	2		55.00	5.00	51.50
		2	50	4		56.40	6.40	51.50
		2	55	2	57.83	60.00	5.00	62.40
		2	55	4	63.85	63.85	8.85	62.40
	Minor Arterial	6	30	2		34.09	4.09	35.70
		6	30	4		34.67	4.67	35.70
		6	40	2		43.83	3.83	43.60
		6	40	4		44.58	4.58	43.60
		6	45	2		48.70	3.70	47.55
		6	45	4		49.53	4.53	47.55
		6	50	2	53.57	53.57	3.57	51.50
		6	55	2	61.38	59.05	4.05	62.40
		6	55	4	63.26	63.26	8.26	62.40
	Major Collector	7	45	2		47.65	2.65	47.55
		7	45	4		48.46	3.46	47.55
		7	50	2	52.41	52.41	2.41	51.50
		7	50	4		53.75	3.75	51.50
		7	55	2	59.05	57.83	2.83	62.40
	Minor Collector	8	40	2		43.83	3.83	43.60
		8	50	2		52.41	2.41	51.50
		8	50	4		53.75	3.75	51.50
	Local	9	40	2		40.00	0.00	43.60
		9	50	2		50.00	0.00	51.50

Table 2 Free-Flow Speed Table (Continued)

Area	Facility	FHWA Functional Class	Posted Speed (mph)	Number of Lanes	Avg. Speed (mph)	Free-Flow Speed (mph)	Speed [1] Differential (mph)	NCHRP [2] (mph)
Urban	Interstate	11	55	2		60.00	5.00	62.40
		11	55	4		64.00	9.00	62.40
		11	55	6		64.00	9.00	62.40
		11	55	8		64.00	9.00	62.40
	Freeway & Expressway	12	55	2		60.00	5.00	62.40
		12	55	4		61.59	6.59	62.40
		12	55	6	61.59	61.59	6.59	62.40
		12	55	8		61.59	6.59	62.40
	Principal Arterial	14	25	2	28.28	28.28	3.28	31.75
		14	25	4		31.19	6.19	31.75
		14	30	2		34.09	4.09	35.70
		14	30	4		34.67	4.67	35.70
		14	35	2		38.96	3.96	39.65
		14	40	2		43.83	3.83	43.60
		14	40	4	50.22	47.71	7.71	43.60
		14	40	6		47.71	7.71	43.60
		14	45	2	48.41	48.41	3.41	47.55
		14	45	4	52.33	52.33	7.33	47.55
		14	45	6		52.33	7.33	47.55
		14	50	4		56.70	6.70	51.50
		14	55	4	61.08	61.08	6.08	62.40
	Minor Arterial	16	40	2		41.66	1.66	43.60
		16	40	4		45.35	5.35	43.60
		16	40	6		45.35	5.35	43.60
		16	45	2		47.65	2.65	47.55
		16	45	4		48.46	3.46	47.55
		16	45	6		48.46	3.46	47.55
	Collector	17	35	2		38.96	3.96	39.65
		17	35	4		41.40	6.40	39.65
	Local	19	35	2		35.00	0.00	39.65

Note: 1. Speed Differential = Free-Flow Speed – Posted Speed
2. For posted speed limits exceeding 50mph:
Free-Flow Speed = 0.88*Posted Speed Limit + 14
For posted speed limits less than or equal to 50mph:
Free-Flow Speed = 0.79*Posted Speed Limit + 12
Source: NCHRP Report 387: Planning Techniques to Estimate Speeds and Service Volumes for Planning Applications, 1997

Capacity and Effective Travel Time Adjustments

The original statewide model used the typical modeling practice of ascribing a roadway capacity based on a simplified link capacity system that in many cases over or under-estimated the true capacity of the roadway. While it was beyond the scope of this study to completely revamp this system, capacities *in the 26-county I-69 Study Area* were modified to take into account signalized intersections, driveways and other access points.

The process by which this was accomplished began by re-setting all links within the Study Area to the ideal service flows specified in the *Highway Capacity Manual* (HCM). Then, these service flows were adjusted based on several of the limiting factors recommended in the *Highway Capacity Manual*. These factors included: lane width, shoulder width, whether or not the roadway is divided, access points and signalization.

These refinements are important in that they allow for a more precise estimation of the beneficial effects of the I-69 alternatives that involve upgrading existing highways from existing conditions to Interstate design standards.

Another significant network improvement has been the incorporation of delays encountered at signalized intersections into the estimation of capacities and "effective free flow travel times". These enhancements make possible the ability to take into account the *removal* of traffic signals associated with certain alternatives in the estimation of travel time benefits. The discussion below outlines the methodologies used for incorporating these enhancements into the model network.

Adjustment for Access Points

Capacity adjustments due to friction at access points on the arterial highway system was accounted for using the 1997 HCM method. Since information on the number of access points per mile is not available, an *area type* designation was used. The area type was determined by TAZ population density thresholds, as computed using the geographic information system (GIS) capabilities of the TransCAD model. Assumptions were made on the number of access points per mile based on the typical characteristics of these area types. Adjustment factors are shown in Table 3.

Table 3 Area Type Adjustment Factors

Area Type	Density Thresholds (population / sq.mi.)	Access Points	Adjustment Factors
Rural	0 to 250	0 to 10	1.00
Suburban	250 to 1,000	10 to 20	0.94
Urban	1,000 to 5,000	20 to 30	0.90
CBD	5,000 or more	30+	0.88

Source: Bernardin, Lochmueller & Associates, Inc., November 2000.

Capacity and Free Flow Travel Time Adjustment for Signalization

Roadway capacity and average link travel times was adjusted by way of a signal, field coded into the model network. Signal data came from a TransCAD geographic layer provided by INDOT showing all signal locations within the State of Indiana. Only those signals within the 26-county area were coded. The travel time adjustment was made by processing the network using the methodology described below.

While all signals in the Study Area were coded, not all local streets are coded into the modeled network. This is especially the case in urban areas and towns, since the statewide model was designed as a rural/suburban planning tool for state highways and was not intended to take the place of local planning jurisdictions. Accordingly, it is possible for a link in the modeled network to contain more than one traffic signal. The more signals on a link of roadway, the more likely a vehicle will have to stop, thus incurring delay. With increasing signal density, it is even possible that a vehicle will be forced to stop more than once.

The travel time adjustment methodology used a weighted mean from a binomial distribution function, which accurately describes the probability of being stopped any number of times on a signalized arterial. The probability of being stopped at a signal with a g/C ratio of 0.6 is (1-0.6) = 0.4. If there are two signals in succession, there is a probability of being stopped at the first signal, the second signal or sometimes both. Assuming the signals on the arterial are not synchronized, the probability of each possible scenario on a link with two signals is described as:

No Stops:	0.6 * 0.6 = 0.36
Stopped by 1st Signal:	0.4 * 0.6 = 0.24
Stopped by 2nd Signal:	0.6 * 0.4 = 0.24
Stopped by both:	0.4 * 0.4 = 0.16

If there are 1,000 vehicles passing through the area in one hour, it is likely that 360 would not be significantly delayed, 240 would be stopped by the first signal, 240 would be stopped by the second signal, and 160 would be stopped by both. In terms of travel time, 480 vehicles are likely to be delayed once and 160 vehicles twice. The average travel time through the area depends on the time it takes to drive the mainline portion of the arterial, based on the link's coded speed, plus the average delay encountered on the stop portion of the signal cycle. (In the presence of congestion, additional delay is incurred; this is an amount of time computed by the trip assignment model as a function of free flow speed, the modeled volume, and the capacity.)

With increasing numbers of signals, the binomial distribution function is described below:

$$P_{stop} = \frac{N!}{x!(N-x)!} P_{red}^{x} \cdot P_{green}^{N-x}$$

where,

P_{stop} = probability that a vehicle will be stopped x number of times;
N = number of signals on the analysis segment;
P_{red} = probability of each signal being red;
P_{green} = probability of each signal being red.

From this function, a simplified equation was derived to calculate the weighted average of time delay due to signalization:

$$T_{signals} = P_{red} \cdot T_{delay}$$

where,

$T_{signals}$ = average additional travel time due to signal(s);
N = number of traffic signals;
P_{red} = probability of being stopped at each signal (1-g/C);
T_{delay} = time (in minutes) that stopped vehicles are delayed at each intersection.

Reduced Roadway Capacity Due to Signalization

The capacity reduction methodology was based on travel speed reductions due to signalized intersection delay. The service flow rate is a function of the travel time along a road segment. Increasing signal densities effectively reduce travel speeds which, in turn, reduces the amount of traffic flow that is possible. The reduction in service flow was calculated by the equation shown below:

$$f_{signals} = \frac{T_{signals}}{T_{signals} + T_{mainline}}$$

where,

$f_{signals}$ = capacity reduction adjustment factor due to signals;
$T_{signals}$ = average additional travel time due to signal(s);
$T_{mainline}$= free flow travel time on the roadway segment.

Four-Step Travel Model

In this section of the report, the "four-step" travel model will be described. Separate sub-sections are included for trip generation, trip distribution, mode choice, and trip assignment.

Trip Generation Models

Trip generation for the initial Indiana Model consisted of trip production and trip attraction models by trip purpose. The trip production model was estimated using cross-classification techniques, while the trip attraction model was estimated using regression techniques. Trip production trip rates were linked to household size and auto ownership by zone. Trip attraction rates were specified as a function of employment by zone. Both trip production and attraction models were developed using the 1995 Indiana Household Survey dataset, which included only households within Indiana.

The trip production and attraction models developed for the initial Indiana Model were used in their original form for the I-69 Evansville to Indianapolis Study. The primary updates to these models implemented for this study considered the following:

- Trip generation procedures for the home-work (HW), home-other (HO), and non-home (NH) trip purposes were extended to include the expanded external areas (in Illinois, Kentucky, Michigan, and Ohio) as described in Section 1.0 of this report; and
- Trip production rates for the HW, HO, and NH trip purposes were combined into a single set of rates for the entire expanded area rather than on a superzone specific basis. This was implemented after further review, comparison, and validation of trip rates from other sources in order to improve the accuracy of the trip generation model.
- Trip production and attraction models were validated using several sources including the 1995 National Planning Transportation Survey (NPTS) and the National Highway Cooperative Research Program (NCHRP) Report 365.

The procedures, inputs, and outputs used in the development and validation of the trip production and trip attraction models are presented below.

Trip Production Model

The trip production model was developed to estimate trips by households for each trip purpose. For the shorter trip purposes (HW, HO, NH), this was implemented for the entire updated Indiana Model including TAZ's in Indiana, Illinois, Kentucky, Michigan, and Illinois. For the Long trip purpose (LT), the trip production model was applied only to TAZ's within Indiana. Trip rates were developed using the following steps:

- Household and trip expansion factors by trip purpose were developed and applied to the 1995 Indiana Household Travel Survey data. Factors were developed to create representative statewide totals for households and trips for model validation purposes.

- Trip production models were developed using a cross-classification structure consisting of household size, auto ownership, and superzone variables from the expanded survey data. Trip rates were calculated by purpose for each variable based on the expanded household and trip totals.

Refer to Section 6.2.1 of the *Indiana Statewide Travel Model Documentation Report* prepared for INDOT on August 25, 1998, for detailed information on Indiana Model trip production development procedures.

Trip Production Data Inputs

The data inputs and model outputs used to develop the trip production models for the updated Indiana Model included:

- **1995 Indiana Household Travel Survey Data.** Data used in this process included the number of households by household size and auto ownership and the number of trips per household by trip purpose.

- **1990 Census Data.** The Census Transportation Planning Package (CTPP) included key cross-tabulations for use in trip production model development including the number of households by household size and auto ownership for the county level and the number of households by household size and auto ownership for the tract level.

- **Woods & Poole Data.** The Woods & Poole database was used to obtain household estimates by county for the base year (1998) and household forecasts by county for the future forecast year (2025).

- **Validation Data.** Trip production models were validated using the 1995 National Planning Transportation Survey (NPTS) and the National Highway Cooperative Research Program (NCHRP) Report 365.

Trip Production Outputs

Tables 4 and 5 show the final validated trip production rates and household size and auto ownership for each trip purpose of the updated Indiana Model. Validated rates reflect the cross-classification trip production models estimated for the updated Indiana Model. The base year trip productions by trip purpose are summarized in Table 6.

Table 4 Validated, Updated Indiana Model Trip Production Rates

Purpose	Household Size	Autos Owned 0	1	2	3+
Home-Work	1	0.9693	0.9693	0.9693	0.9693
	2	0.7737	0.8486	1.9790	1.9790
	3	0.7737	1.6145	2.5521	3.1141
	4+	0.7350	2.0785	2.7924	3.5480
Home-Other	1	1.9905	1.9905	1.9905	1.9905
	2	2.4526	3.5416	3.5416	3.5416
	3	5.8707	5.8707	5.8707	5.8707
	4+	8.6667	10.2916	10.2916	10.2916
Non-Home	1	1.8071	1.8071	1.8071	1.8071
	2	2.4240	2.4240	2.4174	2.2711
	3	2.6432	2.6432	3.0531	3.7938
	4+	2.6929	2.6929	5.0972	5.2577

Source: Cambridge Systematics, Inc., November 2000.

Table 5 Validated, Updated Indiana Model Trip Production Rates for LongTrips

Superzone #	Household Size	Autos Owned 0	1	2	3+
1	1	0.135	0.135	0.135	0.135
	2	0.136	0.136	0.136	0.189
	3	0.136	0.136	0.136	0.189
	4+	0.241	0.241	0.241	0.241
2	1	0.012	0.012	0.012	0.012
	2	0.040	0.040	0.040	0.054
	3	0.040	0.040	0.040	0.225
	4+	0.040	0.040	0.040	0.225
3	1	0.050	0.050	0.050	0.050
	2	0.113	0.113	0.113	0.128
	3	0.113	0.113	0.113	0.128
	4+	0.162	0.162	0.162	0.881
4	1	0.013	0.013	0.013	0.013
	2	0.058	0.058	0.062	0.062
	3	0.058	0.058	0.062	0.062

Superzone #	Household Size	Autos Owned			
		0	1	2	3+
	4+	0.168	0.168	0.168	0.238
5	1	0.054	0.054	0.054	0.054
	2	0.062	0.062	0.062	0.273
	3	0.062	0.062	0.062	0.273
	4+	0.095	0.095	0.095	0.273
6	1	0.081	0.081	0.081	0.081
	2	0.349	0.349	0.349	0.349
	3	0.349	0.349	0.349	0.349
	4+	0.349	0.349	0.349	0.349
7	1	0.043	0.043	0.131	0.131
	2	0.043	0.043	0.131	0.131
	3	0.043	0.043	0.131	0.131
	4+	0.231	0.231	0.231	0.231
8	1	0.055	0.055	0.055	0.055
	2	0.088	0.088	0.111	0.111
	3	0.088	0.088	0.111	0.111
	4+	0.148	0.148	0.148	0.148
9	1	0.033	0.033	0.052	0.052
	2	0.033	0.033	0.052	0.052
	3	0.033	0.033	0.052	0.052
	4+	0.073	0.073	0.073	0.073
10	1	0.022	0.022	0.022	0.022
	2	0.036	0.036	0.117	0.117
	3	0.036	0.036	0.117	0.117
	4+	0.160	0.160	0.160	0.160
11	1	0.013	0.013	0.013	0.013
	2	0.058	0.058	0.058	0.073
	3	0.058	0.058	0.058	0.073
	4+	0.058	0.058	0.058	0.073

Source: Cambridge Systematics, Inc., November 2000.

Table 6 Estimated to Observed Trip Production Results by Trip Purpose of the Updated Indiana Model

Trip Purpose	Trip Productions		Percent Difference
	Observed[1]	Estimated	
Home-Work	4,455,195	4,359,078	-2.16%
Home-Other	12,053,067	11,840,898	-1.76%
Non-Home	6,256,292	6,314,894	0.94%
Long Trips	263,688	263,681	0.00%
Total Trips	23,028,242	22,778,551	-1.08%

[1] Observed total trip productions from expanded household travel survey.

Source: Cambridge Systematics, Inc., November 2000.

Trip Attraction Model

The trip attraction model was estimated to predict the number of trips made to (or attracted to) each TAZ by households for each trip purpose: HW, HO, NH, and LT. The models consisted of regression equations that were estimated using data from the household travel survey, the establishment-based employment data from Dun & Bradstreet, and the county-level employment data from the Woods and Poole dataset. These procedures were not revised from the initial Indiana Model for this modeling effort. Refer to Section 6.2.2 of the *Indiana Statewide Travel Model Documentation Report* prepared for INDOT on August 25, 1998, for detailed information on Indiana Model trip attraction development procedures.

Trip Attraction Data Inputs

The data inputs and model outputs used to develop the trip attraction models for the updated Indiana Model included:

- **1995 Indiana Household Travel Survey Data.** The 1995 Indiana household travel survey provided information on the geographic location of trip attractions for responding households.

- **Woods & Poole Economics Data.** The Woods & Poole database consisted of a historical database of annual forecasts of employment by sector by county from 1998 to 2025.

- **Dun & Bradstreet Employment Data.** The Dun & Bradstreet database included establishment-level estimates of employment, sector of business (SIC code), and geographic information.

Trip Production Outputs and Results

Table 7 shows the final regression parameters for the validated attraction models of the updated Indiana Model.

Table 7 Regression Models for Trip Attractions by Trip Purpose for the Updated Indiana Model

Variable	Parameter Estimate	Standard Error	T for H_0: Parameter=0
Home Work Trips			
Intercept	0.0	(Constrained)	
Employment in Farm and Industrial Sectors	1.650857	0.33245659	4.966
Employment in Government Sectors	2.269890	1.04285920	2.177
Employment in Non-industrial Sectors	0.598890	0.26878348	2.228
Adjusted R^2	0.9389		
Home Other Trips			
Intercept	0.0	(Constrained)	
Employment in Farm and Industrial Sectors	0.391102	1.05392742	0.371
Employment in Non-industrial and Government Sectors	0.197753	0.50082205	0.395
Households	4.878835	0.84811869	5.753
Adjusted R^2	0.9490		
Non-Home Trips			
Intercept	0.0	(Constrained)	
Employment in Farm and Industrial Sectors	1.375648	0.39251245	3.505
Employment in Non-industrial and Government Sectors	1.727858	0.15434426	11.195
Adjusted R^2	0.9596		
Long Trips			
Intercept	0.0	(Constrained)	
Total Employment	0.407612	0.01768814	23.044
Adjusted R^2	0.8521		

Source: Cambridge Systematics, March 1998 and November 2000.

Trip Distribution Models

The initial Indiana Model used the gravity model for trip distribution to develop trip matrices for internal Indiana TAZs. Gravity models were refined in the updated Indiana Model to consider the following improvements:

- For the longer inter-city trips (LT), the validated gravity model procedures from the initial Indiana Model were retained to distribute trips internal to Indiana. The distribution of LT trips with a trip-end outside of Indiana (Illinois, Kentucky, Michigan, and Ohio) were estimated using the relationships contained in the Corridor 18 Study Regional Travel Model. These trip matrices were merged with the internal to Indiana trips in a later modeling step.

- The gravity models for the HW, HO and NH trip purposes were re-estimated for the entire expanded study area including external (Illinois, Kentucky, Michigan, and Ohio) and internal zones to Indiana.

Gravity models were used for trip distribution of the initial and updated Indiana Models. Gravity models were calibrated and run for each of the trip purposes modeled: HW, HO, NH, and LT. The gravity model is the most widely used model for trip distribution. Based on Newton's law of gravitation, it assumes that the trips from a TAZ (trip productions) are distributed to other TAZs (trip attractions) in direct proportion to the size of the attraction TAZ and in inverse proportion to the spatial separation between adjacent TAZs. In general, the number of trips attracted to a TAZ represents the size of the attraction TAZ and the interzonal travel time of the spatial separation.

The following section describes the development of the gravity models and shows the results of the validation of these models. Refer to Section 6.2.3 of the *Indiana Statewide Travel Model Documentation Report* prepared for INDOT on August 25, 1998, for detailed information on Indiana Model trip distribution development procedures.

Trip Distribution Data Inputs

The trip distribution modeling process incorporated the following data inputs and modeling elements:

- **1995 Indiana Household Travel Survey Data.** Observed trip lengths by trip purpose from the 1995 Indiana household travel survey;

- **Updated Trip Productions and Attractions.** Production and attraction trip ends by trip purpose and TAZ from the trip generation models of the updated Indiana Model;

- **Updated Transportation Network Travel Times.** Travel times were computed using the updated transportation network for the Indiana Model.

- **Updated Friction Factors.** Updated and validated friction factors calibrated for each trip purpose using gravity model procedures;

- **K-Factors.** Adjustment factors (K-factors) for the HW, HO, and NH trip purposes developed as part of the overall model validation process; and

- **Gravity Model Applications.** Gravity model applications by trip purpose using TransCAD procedures.

The gravity models were validated with interzonal travel times and distances obtained from the 1995 Indiana household travel survey. Calibrated friction factor lookup tables were output from this process for the updated Indiana Model. The calibrated friction factor lookup tables were then input, along with the trip productions and attractions and travel times, into the gravity model application runs for each trip purpose. For the HW, HO and NH trip purposes, k-factors were also incorporated into the trip distribution validation process. This step resulted in the development of production and attraction trip matrices in TransCAD format used for input in the mode choice element of the four-step modeling process.

Trip Distribution Adjustment Factors

Adjustment factors or K-factors were used in trip distribution calculations to adjust origin and destination trip interchanges not replicated very well in the gravity modeling process. K-factors are often used where bridges, other perceived travel barriers, or special socioeconomic factors (such as housing prices) may distort the distribution of trips between specific areas in a given modeling area.

K-factors were developed as part of the updated Indiana Model to represent zone-to-zone adjustments for selected interchanges. These trip distribution refinements from the initial Indiana Model were necessary to better represent trip distribution in the expanded transportation network of the updated Indiana Model that included areas outside of Indiana where the network characteristics were very different. Without these adjustment factors, trip movements across state boundaries, especially in the sub-urban Chicago area, were consistently over estimated. Other k-factors were developed to enhance or inhibit unrealistic travel between areas on a super-district level.

Trip Distribution Outputs and Results

Tables 8 and 9 compare the resulting trip lengths to observed trip lengths by purpose of the initial and updated Indiana Models. The person trip tables generated from this process were input into mode choice modeling analysis. These person trip tables also were used as control and check totals for trip making during mode choice model validation.

Table 8 Gravity Model Application Results of the Updated Indiana Model for HW, HO, and NH Trip Purposes

Trip Purpose	Observed Average Distance (miles)[2]	Base Year Model Average Distance (miles)
HW	12.5	15.8
NH	10.0	10.3
NH	10.0	10.3

Source: Cambridge Systematics, Inc. November 2000.

Table 9 Gravity Model Application Results of the Updated Indiana Model for LT Trip Purpose

Trip Purpose	Observed Average Time (minutes)[2]	Base Year Model Average Time (minutes)
LT	127.7	134.3

Source: Cambridge Systematics, Inc., November 2000.

Mode Choice Models

A new set of mode choice models were implemented for the updated Indiana Model to meet the needs of the expanded study area transportation network and to better represent intercity travel in Indiana. These models were also refined to better address regional issues associated with the I-69 Evansville to Indianapolis corridor. Additional considerations for developing updated mode choice models included:

- The models were adjusted to be more policy-sensitive by reflecting the competition among highway and transit modes including the better representation of variables related to highway and transit level of service and the socioeconomic characteristics of the population under study;
- The models were validated for the base year (1998) to reflect the existing market shares of highway and transit modes within a reasonable degree of accuracy in the I-69 Evansville to Indianapolis Study Area; and
- The models were revised to better represent future forecasting in Indiana including the implementation of explanatory variables for which future year level of service and socioeconomic data were available as inputs.

The initial Indiana Model mode choice element was considered inappropriate by INDOT to meet the above stated needs. The decision was made to develop a new set of procedures that better suited the intercity focus of the I-69 Evansville to Indianapolis Study and other corridors in Indiana. Most importantly, a multinomial logit (MNL) mode choice model was developed for the LT purpose in order to estimate the probability that a traveler would choose a particular mode of travel for the longer trips between cities. For the shorter trips within cities, MNL models were not implemented. Rather, auto and transit usage data obtained from the 1995 Indiana household travel survey were applied to the HW, HO, and NH trip purpose to generate mode shares.

The approach used in developing the mode choice model for the LT purpose involved borrowing coefficients from a previously developed model, adjusting and calibrating the modal bias constants using the 1995 Indiana household travel survey data and observed aggregate mode shares, and developing model application procedures and inputs within TRANSCAD. This process was consistent with the procedures used to estimate the mode choice models for the HW, HO, and NH trip purposes of the initial Indiana Model. For more information about these model development and application steps, refer to Section 6.2.4 of the *Indiana Statewide Travel Model Documentation Report* prepared for INDOT on August 25, 1998, for detailed information on Indiana Model mode choice development procedures.

Mode Choice Data Inputs

The following data items included some of the inputs and resulting outputs from the trip distribution models presented in Section 2.2:

- **1995 Indiana Household Travel Survey Data.** The 1995 Indiana household travel survey was used to identify auto occupancies, to develop travel time factors, and to determine HW, HO, and NH trip purpose mode splits to be applied during mode choice model development. The surveyed auto occupancies by trip purpose used in this modeling process included:
  - HW – overall auto occupancy was 1.20;
  - HO – overall auto occupancy was 2.15;
  - NH – overall auto occupancy was 1.87; and
  - LT – overall auto occupancy was 3.06.

  The following HW, HO, and NH observed mode shares were used in the mode choice modeling process rather than the MNL model estimation process:

  - HW - 99 percent for the auto (SOV and HOV) mode and 1 percent for the transit mode;
  - HO - 92 percent for the auto mode and 8 percent for the transit mode; and
  - NH - 96 percent for the auto mode and 4 percent for the transit mode.

The above information was used to develop travel time and cost factors for the transit modes to be modeled.

- **Highway Network Travel Times.** Application of the updated mode choice models required the calculation of travel time matrices by mode and trip purpose to identify travel between each TAZ pair. Travel time matrices for auto travel modes were obtained from the highway network developed for trip distribution, as described earlier.

- **Transit Network Travel Times.** A transit network was developed based on current intercity transit services within Indiana. Travel time matrices by transit modes were calculated using this transit network developed specifically for the updated Indiana Model. In particular, the existing AMTRAK and Greyhound intercity train and bus service were coded into the TRANSCAD transit network. In-vehicle travel times (IVTT) between stations were calculated by reporting the free-flow highway network travel times. Transit station access time or out-of-vehicle travel time (OVTT) was calculated by reporting the highway travel time from TAZ's within a 10 mile radius of each transit station. Both IVTT and OVTT are inputs into the MNL. Transportation Network Travel Costs.

- **Transportation network Travel Costs.** Travel cost matrices were computed from the highway and transit travel time matrices. For auto costs, this computation included 30 cents per mile divided by the average vehicle occupancy for the specific trip purpose. Transit costs were estimated from current train and bus schedules and adjusted during the validation process to arrive at a value of 19.5 cents per mile.

- **Transferred Mode Choice Models.** Mode choice model coefficients for the LT trip purpose were transferred from the California High Speed Rail Study Model developed by Charles River Associates. This is the most recent study in North America that investigates the determinants of mode choice in an intercity context. Person Trip Productions and Attractions

- **Updated trip Matrices by Trip Purpose.** The person trip productions and attractions by TAZ pair generated during trip distribution were input into mode choice. These trips were used as the person trip control totals during mode choice modeling.

Mode Choice Outputs and Results

Person trip tables by each trip purpose (HW, HO, NH, and LT) and mode were created from the mode choice modeling process. The base year (1998) mode choice modeling results, by total number of trips and mode share for the LT trip purpose appear below:

- **Auto Mode** – 90.6 percent observed to 90.5 percent estimated; and

- **Transit Mode** – 9.4 percent to 9.6 percent estimated.

The observed data were obtained from the 1995 Indiana household travel survey. Table 10 shows the various cost and travel time matrices that were used as inputs into the MNL model for the LT trip purpose of the updated Indiana Model. Table 2.8 shows the initial constants and coefficients transferred from the California High Speed Rail Study Model and the final bias constant applied during the calibration of the updated Indiana Model.

Table 10 Updated Indiana Model Base Year Impedance Matrices[1]

Matrix File	Component Matrix	Contents
TIMES.MTX	FFLOW	Skim of free flow highway travel time
	CTIME	Skim of congested highway travel time
	IVTT	Skim of free flow highway travel time between stations
	OVTT	Skim of highway free flow travel time between TAZ's and stations
COST.MTX	AUTO	Skim of distance * 30
	TRANSIT	Skim of distance * 17

[1] The travel times developed were developed from the base year transportation network. The "congested" travel times were present in the original base year highway database (as received from BLA) and were general, higher than free flow travel times that were later calculated and added to the base year database.

Source: Cambridge Systematics, Inc., November 2000.

Table 11 Updated Indiana Model Mode Choice Model Parameters

Variable	Non-Business/Drivers
	Long Trips
Cost ($)	-0.0276
Line haul time (min.)	-0.0069
Access/egress time (min.)	-0.0083
Bias Constant	-0.87

Source: Cambridge Systematics, Inc., November 2000.

Time-of-Day Models

Time-of-day (TOD) factors developed for the initial Indiana Model were retained in the updated Indiana Model. These TOD factors were developed by trip purpose and time period using the 1995 Indiana Household Travel Survey. The updated Indiana Model currently allocates daily trips for the a.m. peak, p.m. peak, and off-peak periods. These models are applied after mode choice prior to trip assignment.

Refer to Section 6.2.5 of the *Indiana Statewide Travel Model Documentation Report* prepared for INDOT on August 25, 1998, for detailed information on Indiana Model time-of-day model development procedures. Tables 12 and 13 show the calibrated TOD factors used for the updated Indiana Model.

Table 12 Time-of-Day Production/Attraction Factors by Trip Purpose

Period	Percent Traffic by Purpose and Direction and Time Period									
	HW			HO			NH	LT		
	P to A	A to P	Total	P to A	A to P	Total	Total	P to A	A to P	Total
AM	31.74%	1.43%	33.17%	19.30%	2.16%	21.46%	12.06%	6.87%	0.12%	6.99%
PM	2.76%	27.49%	30.25%	9.34%	18.40%	27.73%	25.17%	11.04%	12.69%	23.73%
Off-peak	18.54%	18.04%	36.58%	20.71%	30.09%	50.80%	62.77%	32.09%	37.19%	69.28%
Total	53.04%	46.96%	100.00%	49.35%	50.65%	100.00%	100.00%	50.00%	50.00%	100.00%

Source: Cambridge Systematics, Inc., November 2000.

Table 13 Converted Time-of-Day Origin/Destination Factors by Trip Purpose

	Percent Traffic by Purpose and Direction and Time Period Normalized by Time Period						
	HBW		HBO		NHB	Long Trips	
	P to A	A to P	P to A	A to P	Total	P to A	A to P
AM	95.68%	4.32%	89.93%	10.07%	12.06%	98.28%	1.72%
PM	9.13%	90.87%	33.67%	66.33%	25.17%	46.52%	53.48%
Off-peak	50.68%	49.32%	40.76%	59.24%	62.77%	46.32%	53.68%
Total	53.04%	46.96%	49.35%	50.65%	100.00%	50.00%	50.00%

Source: Cambridge Systematics, Inc., November 2000.

External Models and Cumulative Demand

The HW, HO, and NH trips to/from Indiana to/from adjacent states, in particular eastern Illinois, western Kentucky, southern Michigan, and western Ohio, were modeled as internal-to-internal movements in the updated Indiana Model. These trips were estimated using traditional four-step modeling procedures for trip generation, trip distribution, and mode choice elements of the updated Indiana Model. This process represents a complete revision of the external-internal models developed in the initial Indiana Model that were based on the incremental modeling approach no longer applied in the updated Indiana Model.

Long trips with one or more trip-ends outside of Indiana were estimated separately using trip matrices from the Corridor 18 Study Regional Travel Model. Corridor 18 Study Regional Travel Model trip tables were used to obtain internal-external, external-internal, and external-external trips for the LT trip purpose. Trips were represented at the county level in the Corridor 18 Study and at the smaller TAZ level within Indiana. Trip tables were manipulated using the following procedures to make them consistent with the updated Indiana Model:

- The trip movements from the Corridor 18 Study Regional Travel Model corresponded to a base year of 1994 and a future year of 2020. The base and future years for the updated Indiana Model were 1998 and 2025, respectively. Trip tables were factored from 1994 to 1998 and 2020 to 2025 based on the development of annualized growth factors.

- County level trip tables were disaggregated to the updated Indiana Model TAZ level using available socioeconomic data. Trip origins were allocated to the TAZ level based on the relative population within the county while trip destinations were allocated to the TAZ level based on total employment.

- Time-of-day factors developed from the 1995 Indiana household travel survey were applied to obtain external trips by time period. Since the trip tables from the Corridor 18 Study Regional Travel Model were already in origin-destination format, it was not necessary to apply PA to OD conversion factors.

Similar to the initial Indiana Model, external stations were coded into the transportation network outside of the detailed, expanded external modeling areas in Illinois, Kentucky, Michigan, and Ohio. Trip movements for these external stations were obtained from the Corridor 18 Study Regional Travel Model trip tables. This process was used to generate external-internal, internal-external, and external-external movements in the updated Indiana Model. This process will also be used to assess the potential cumulative demand associated with future transportation alternatives to be assessed in the next phase of the I-69 Evansville to Indianapolis Study.

Truck Models

As in the initial Indiana Model, truck trip tables were developed for internal Indiana areas using the aggregate (county-level) truck activity and commodity flow models developed by Dr. William Black of Indiana University as part of the *Transport Flows in the State of Indiana: Commodity Database Development and Traffic Assignment – Phase* 2 Project. Procedures were, however, updated to allocate the truck trips from the county level to the TAZ level. For those trip movements not internal to Indiana, the Corridor 18 Study Regional Travel Model trip tables were used to support the updated Indiana Model.

Refer to Section 7.0 of the *Indiana Statewide Travel Model Documentation Report* prepared for INDOT on August 25, 1998, for detailed information on Indiana Model truck model development procedures. As stated previously, the foundation for the truck activity models were the 1993 and 2015 truck trip tables developed by Dr. William Black. TransCAD procedures were used to perform several functions in the updated Indiana Model. These procedures included:

- Formatting base year truck data from the trip tables developed by Dr. Black to the county-level maintained in the updated Indiana Model;
- Allocating base year county-level truck trip tables to the TAZ level using Dun & Bradstreet establishment data;
- Allocating county level external truck movement data from the Corridor 18 Study Regional Travel Model to the TAZs established in the updated Indiana Model;
- Developing base year truck "seed" matrices for input into the TransCAD Origin Destination Matrix Estimation (ODME) procedure to estimate 1998 truck trip tables;
- Estimating 2025 Indiana Model truck trip tables using the TransCAD growth factor procedures;
- Applying truck time-of-day factors using TransCAD matrix manipulation procedures to split the daily trip tables by a.m. peak, p.m. peak, and off-peak period; and
- Assigning truck trip tables to the transportation networks using TransCAD user equilibrium assignment procedures.

The above truck modeling process was used to generate truck trip matrices for base and future year trip assignment in the updated Indiana Model.

Truck Model Data Inputs

The data inputs for truck trip table development included:

- **Dr. Bill Black Internal Indiana Truck Movement Data.** Truck movements from the Dr. Black study were used to identify truck movements in Indiana. These databases were also used to estimate the future annual growth factors for truck activities in the state of Indiana.

- **Corridor 18 Study External Indiana Truck Movement Data.** Truck movements external-to-Indiana were obtained from the Corridor 18 Study Regional Travel Model. These trip tables were used to develop portions of the base year seed trip table as well as to estimate the future annual growth factors for truck movements external to Indiana. Factors were applied to base year calibrated truck trip tables to forecast future truck movements.

- **Dun & Bradstreet Employment Data.** Employment and establishment location data contained in the Dun & Bradstreet datasets were used to distribute the county-level truck movement flows to TAZs.

- **Regional Economic Model, Inc. Data.** Input/Output data were obtained from the current REMI model for the state of Indiana used in MCIBAS.

- **Observed Truck Counts.** Estimated truck traffic counts entered into the transportation networks were used to calibrate base year truck movements using TransCAD ODME procedures.

- **Transportation Networks.** The TransCAD roadway database was used to prepare the transportation networks required during the trip assignment of both base- and future-year truck matrices.

- **Time-of-Day Factor Data.** Time-of-day factors for the a.m. peak, p.m. peak, and off-peak periods were obtained from the Federal Highway Administration (FHWA) sponsored *Quick Response Freight Manual* to split the daily truck trip tables by time-of-day.

Updated Truck Model Procedures

The following procedural steps were implemented to estimate both the 1998 and 2025 updated Indiana Model:

1. **Format County-to-County Truck Movement Matrix.** In the *Transport Flows* project, Dr. Black estimated truck movements at the county-to-county level in Indiana for both 1993 and 2015. Using annualized growth factors derived from this data, 1998 and 2025 truck trip tables were developed and translated into TransCAD matrix format.

2. **Allocate Internal Indiana County Level Truck Movements to the TAZ Level.** The county-level truck trip matrix was disaggregated to the TAZ level using the employment data for 1998 and 2025 and with information from the REMI model for the state of Indiana. Trip origins were allocated to the TAZ level based on the corresponding employment type to the commodity type being transported. Trip destinations were allocated to the TAZ level based on the corresponding employee type for the good or service being produced from the commodity type as estimated by the input/output dynamic from the REMI model.

3. **Allocate Corridor 18 Study External to Indiana Truck Movements to TAZs.** The county level internal-external, external-internal and external-external truck trip movements from the Corridor 18 Study Regional Travel Model were factored to represent 1998 and 2025 and disaggregated consistent with the TAZ system of updated Indiana Model using the same procedures described in Section 2.5 of this report.

4. **Develop Truck Origin/Destination "Seed" Matrix.** The internal and external truck trip matrices were combined into a single trip table. The 1998 base year trip table was used as the daily "seed" trip matrix for the TransCAD ODME procedure to estimate truck travel on the Indiana transportation network.

5. **Run Truck Movement ODME Procedure.** TransCAD ODME procedures were used to adjust the truck movement "seed" matrix to match the daily truck counts contained in the transportation network of the updated Indiana Model. The truck counts originated in the INDOT roadway database file. The truck movement matrix output from this process was validated by roadway functional class. This process was used to generate validated 1998 daily truck movement matrices.

6. **Develop Future Truck Movement Matrix.** The increase in truck trips between 1998 and 2025 for each zone pair was calculated and then added to the 1998 ODME to create the future year daily truck trip table for 2025.

7. **Develop Truck Time-of-Day Models.** Time-of-day factors for the morning and afternoon peak periods and off-peak periods were developed using procedures from the FHWA sponsored *Quick Response Freight Manual.* These factors were used to disaggregate the daily truck movement matrices by time period for trip assignment purposes. The shares derived for all trucks with six or more tires for a.m. peak, p.m. peak, and off-peak periods were 17.14 percent, 16.55 percent, and 66.33 percent, respectively.

Truck Model Outputs and Results

Table 14 shows the results of the truck model estimation process for the 1998 base year.

Table 14 1998 Truck Model Estimation Results of the Updated Indiana Model

Roadway Type	# of Segments	Mean Count	Mean Load	% RMSE	Avg. Deviation	% Deviation	VMT % Deviation
Rural Interstate	141	6,747	6,133	29	-614	-9	-10
Rural Principal Arterial	444	1,524	1,447	25	-77	-5	-4
Rural Minor Arterial	531	610	572	35	-38	-6	-8
Rural Major Collector	984	224	196	59	-28	-13	-11
Urban Interstate	63	8,323	7,281	36	-1042	-13	-10
Urban Principal Arterial	48	2,803	2,500	27	-303	-11	-12
Urban Minor Arterial	147	1,190	1,086	34	-104	-9	1
Urban Major Collector	37	625	268	211	-356	-57	-63
Total	2409	1,266	1,148	60	-118	-9	-8

Source: Cambridge Systematics, Inc., November 2000.

Trip Assignment Models and Validation

This section describes the assignment procedures and validation results of the updated Indiana Model. Validation was conducted for each step in the modeling process and involved initial specification and refinement of the parameters and coefficients by comparing modeling results with observed data. Where applicable, validation of the individual modeling steps was described in the preceding sections of this report. To validate the updated Indiana Model in its entirety, the modeling system was run from start to finish and the individual models were further refined until a good comparison was achieved between model outputs (highway volumes) and observed conditions (traffic counts). Once validated, the model will be used to predict future travel patterns of I-69 corridor alternatives with a high degree of confidence.

Trip Assignment

The origin and destination vehicle trip tables by time period were assigned to the appropriate peak period network to obtain link volumes using the user equilibrium assignment process built into TransCAD. These procedures, developed as part of the initial Indiana Model, included:

- Truck trip tables were assigned before autos;
- Truck volumes on links were used as pre-loads prior to the auto assignment;
- Capacities for the peak period trip assignments corresponded to three-hour peak periods;
- Peak period capacities were obtained by multiplying the peak hour capacities by a factor of three;
- Daily capacities were used for the off-peak period trip assignments since capacity was not considered a constraint for off-peak travel;
- Values for the alpha and beta volume delay functions in the TransCAD trip assignment were specified by functional class; and
- A convergence value of 0.1 and a maximum of 35 iterations were specified for the trip assignments.

Trip Assignment Data Inputs

The data inputs used in the trip assignment and validation process included:

- **Four-Step Model Generated Vehicle Trips.** Updated origin-destination highway trip matrices for the daily and peak-period time periods, including automobile and truck trips, were a primary input in this process.

- **Highway networks.** Updated highway networks customized for the daily and peak periods, including the free-flow travel time and the capacity for each link, were a primary input in this process.

- **TransCAD Validation Functions.** Inputs required by TransCAD including the validation parameters for the BPR volume delay functions that varied by functional class were used in the validation process.

- **Daily Traffic Counts.** Detailed daily traffic counts on the southwestern Indiana portion of the updated Indiana Model were input into the highway network for trip assignment and validation.

Table 15 Traffic Screenline Calibration Criteria

Observed Traffic Estimated Modeled Counts (ADT)	Volume Percentage Thresholds[1]
5,000	35%
10,000	35%
20,000	25%
30,000	20%
40,000	17%
50,000	17%
60,000	15%
70,000	15%
80,000	15%
90,000	15%
100,000	15%

[1] Percentage thresholds relate to the approximate error for acceptable percentage differences (+/-) between observed traffic counts and modeled volumes.

Source: Cambridge Systematics, Inc., November 2000.

Trip Assignment and Validation Outputs and Results

A total of 14 traffic screenlines, consisting of a collection of 6 north-south and 8 east-west directional roadway links of different facility types, were established to validate the updated Indiana Model. The 1998 daily trip table was validated by comparing the percentage difference between balanced, observed traffic count targets and estimated model volumes at the specified screenline locations. The criteria for the acceptable percentage difference between observed and estimated traffic volumes varied by facility type, according to the magnitude of traffic volume usage. For example, higher volume roadways have stricter calibration guidelines than those with lower volumes. Specific percentage thresholds for calibration that were followed in the development of base year trip tables for the Indiana Model are shown in Table 15. These criteria met or exceeded the standards set by the FHWA and other parties for model validation.

Table 16 Screenline Comparison of Observed Traffic Volumes to Modeled Volumes

Screenline	Average Volume	Average Loading	Average Error	% Error	VMT	Average Error	% Error
EW-1	29,029	37,612	8,583	29.6%	296,060	41,737	14.1%
EW-2	10,985	9,633	-1,352	-12.3%	255,601	40,196	15.7%
EW-3	6,745	6,866	120	1.8%	366,320	-8,363	-2.3%
EW-4	5,069	5,542	473	9.3%	428,036	67,294	15.7%
EW-5	7,696	8,489	793	10.3%	545,923	22,847	4.2%
EW-6	21,616	23,025	1,408	6.5%	592,602	-50,589	-8.5%
EW-7	6,511	7,380	869	13.3%	414,421	72,725	17.5%
EW-8	14,497	15,716	770	5.1%	318,885	6,054	1.9%
NS-1	14,398	14,536	138	1.0%	752,048	3,686	0.5%
NS-2S	5,070	4,233	-837	-16.5%	313,274	691	0.2%
NS-3N	9,399	7,842	-1,557	-16.6%	788,369	182,361	23.1%
NS-3S	5,579	5,415	-164	-2.9%	349,705	6,446	1.8%
NS-4N	22,707	22,637	-69	-0.3%	1,011,385	78,801	7.8%
NS-4S	11,738	13,343	1,606	13.7%	427,453	-341	-0.1%
NS-5N	9,946	9,296	-650	-6.5%	1,194,701	11,809	1.0%
NS-5S	8,259	7,231	-1,027	-12.4%	115,055	-27,277	-23.7%
NS-6	6,456	5,741	-714	-11.1%	735,632	-103,005	-14.0%
ALL	11,277	11,515	238	2.1%	8,905,026	345,074	3.9%

Source: Bernardin, Lochmueller & Associates, Inc., February 2001.

The difference between the "estimated" and the observed traffic counts for the screenlines were compared to these calibration criteria identified earlier in Table 15. Table 16 compares the observed traffic counts to the estimated volumes for each screenline. For the updated Indiana Model as a whole, the estimated vehicle-miles of travel from the model were within 4.9% percent of total observed vehicle-miles (where counts exist).

Table 17 Functional Classification Comparison of Observed Traffic Volumes to Modeled Volumes

Functional Classification	Average Volume	Average Loading	Average Error	% Error	VMT	Average Error	% Error
Rural Interstates	24,491	24,353	-138	-0.6%	4,692,192	260	0.0%
Rural Principal Arterial	10,436	9,662	-774	-7.4%	5,202,262	-61,095	-1.2%
Rural Minor Arterials	7,941	6,577	-1,364	-17.2%	2,848,238	-344,452	-12.1%
Rural Major Collectors	2,965	2,422	-543	-18.3%	4,362,301	-334,023	-7.7%
Rural Minor Collectors	3,429	4,007	578	16.9%	241,384	13,902	5.8%
Rural Local Roads	1,927	574	-1,352	-70.2%	16,139	-13,006	-80.6%
Urban Interstates	85,697	89,366	3,669	4.3%	10,539,592	53,721	0.5%
Urban Free/Expressways	25,479	25,199	-281	-1.1%	706,072	56,791	8.0%
Urban Principal Arterials	21,974	20,446	-1,529	-7.0%	7,433,715	-866,036	-11.7%
Urban Minor Arterials	15,472	13,062	-2,410	-15.6%	2,643,535	-753,386	-28.5%
Urban Collectors	7,583	5,363	-2,220	-29.3%	245,135	-65,384	-26.7%
ALL[1]	13,683	12,844	-839	-6.1%	38,930,563	-2,312,709	-5.9%

Source: Bernardin, Lochmuelleer & Associates, Inc., February 2001.

[1] Averages are weighted by the number of observations in each category.

In addition to the screenline analysis, statistics were generated based on the procedures specified in the calibration section of the Indiana Reference Modeling System (IRMS). These validation procedures were designed to measure how well the assigned trip table matches the observed traffic volumes. The focus was not in obtaining a perfect match at the individual link level, but to achieve a good overall fit at the network level.

Table 18 Volume Group Comparison of Observed Traffic Volumes to Modeled Volumes

Volume Group	Average Volume	Average Loading	Average Error	% Error	VMT	Average Error	% Error
< 1,000	591	795	204	34.5%	368,622	142,254	38.6%
1,000-2,500	1,672	1,528	-144	-8.6%	1,299,842	-80,823	-6.2%
2,500-5,000	3,685	3,487	-199	-5.4%	2,845,243	1,219	0.0%
5,000-10,000	7,236	6,221	-1,015	-14.0%	4,491,554	-389,716	-8.7%
10,000-20,000	16,231	14,664	-1,567	-9.7%	10,014,342	-1,100,417	-11.0%
20,000-50,000	32,898	30,668	-2,229	-6.8%	9,210,927	-682,537	-7.4%
> 50,000	91,180	91,588	409	0.4%	10,711,419	-214,075	-2.0%
All Groups	13,683	12,844	-839	-6.1%	38,941,949	-2,324,095	-6.0%

Source: Bernardin, Lochmueller & Associates, Inc., February 2001.

In generating these summaries, only links that have specified traffic counts were used. Table 16 provides the overall statistics for all links with counts. Table 17 provides statistics by FHWA functional class. Table 18 provides statistics by volume group and Table 19 provides statistics for the major highway corridors in the I-69 Study Area. Each table provides the following information:

- Mean observed count by category;
- Mean model loading;
- Average deviation of load from observed count;
- Percentage deviation of load from observed count;
- Total vehicle-miles of travel (VMT);
- Average deviation of total VMT, and;
- Percentage deviation of vehicle-miles of travel (VMT).

Table 19 Comparison of Highway Corridors in the I-69 Study Area: Observed Traffic Volumes to Modeled Volumes

Highway Corridor	Average Volume	Average Loading	Average Error	% Error	VMT	Average Error	% Error
I-465	108,396	104,210	-4,187	-3.9%	5,320,228	-487,958	-9.2%
I-70	60,572	69,179	8,606	14.2%	4,105,662	442,024	10.8%
SR 37	24,764	25,901	1,137	4.6%	1,352,496	57,047	4.2%
SR 57	7,095	6,266	-829	-11.7%	444,585	-18,616	-4.2%
SR 67	11,628	12,141	513	4.4%	722,519	19,042	2.6%
US 231	8,920	7,242	-1,678	-18.8%	1,121,149	-35,041	-3.1%
US 41	20,185	20,872	686	3.4%	1,595,101	24,197	1.5%
US 50	9,057	7,850	-1,207	-13.3%	625,621	-34,728	5.6%

Source: Bernardin, Lochmueller & Associates, Inc., February, 2001

The average percentage deviations of the updated Indiana Model were well within the acceptable limits set by NCHRP 255 and the FHWA for all functional classifications and volume groups. The percentage deviations and VMT deviations generally move in the same direction, indicating that the average trip length derived from validation was close to the actual trip length.

Other Issues

Socioeconomic Forecasts and Databases

Base (1998) and future (2025) year socioeconomic forecasts of population and employment data were used to drive the travel demand modeling process for passenger and truck movements in the updated Indiana Model. The procedures used to develop the zonal socioeconomic datasets for the initial Indiana Model were used to prepare new base and future forecast year socioeconomic datasets.

Datasets for 1998 and 2025 were prepared to support the I-69 Evansville to Indianapolis Study and to support the update of the Indiana Model. For example, socioeconomic data for all internal to Indiana TAZs were updated to reflect 1998 and 2025 information. Datasets within the expanded external areas in Illinois, Kentucky, Ohio, and Michigan were also prepared to represent 1998 and 2025 conditions. Refer to Section 3.0 of the *Indiana Statewide Travel Model Documentation* prepared for INDOT in August 1998 for more information regarding the development of socioeconomic data.

Future Forecasting Process

The updated Indiana Model has a defined future forecasting process that can be used to generate separate future trip tables and trip assignments for each transportation alternative. This particular process follows the state-of-the-practice in travel modeling. Following this process will enable INDOT to better understand the implications of land use and travel behavior shifts caused by level of service changes to the transportation network and population and employment changes to the modeling area.

The process involves running the updated Indiana Model for each proposed alternative starting with trip distribution through mode choice, time-of-day, and trip assignment. This ensures that the travel behavior shifts caused by the different transportation levels of service for each alternative will be modeled and assessed. If land use impacts and shifts need to be understood for a given alternative in the future forecasting process, then trip generation will be the starting point for modeling. This is the recommended modeling strategy for generating future forecasts for each of the transportation alternatives evaluated for the I-69 Evansville to Indianapolis Study.